Adaptive TDMA and CSMA-Based MAC Protocols for Vehicular Ad Hoc Networks: A Survey

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Abstract. Vehicle Ad Hoc Network (VANET) created between vehicles or between vehicles and centralized infrastructures is a dynamic network. Specifically, VANET can support many services such as safety, traffic management, and user-oriented services to improve transportation efficiency. Medium Access Control (MAC) protocol in VANETs not only responds the different requirements of these services but also improves the efficient broadcasting safety messages. One such protocol is to employ both TDMA and CSMA schemes in the Control CHannel (CCH), called a hybrid MAC protocol. A vehicle will send safety message without collision on the TDMA-based period during its reserved time slot and utilize the SCH resources on the CSMA-based period for the non-safety message. In addition, the TDMA-based period can be adjusted according to vehicle density. Hence, these systems can adapt themselves to various traffic conditions and improve the throughput for safety messages. In this survey, we compare different hybrid MAC protocols using dynamic TDMA-based periods as well as their benefits and limitations. Finally, we discuss some issues and promising future research which can be satisfied different QoS requirements and efficiently support both safety and non-safety services.

Keywords: VANET · MAC protocols · Dynamic TDMA-based period · Various traffic conditions

1 Introduction

Intelligent Transportation System (ITS) application is used to provide safe and comfortable driving. Vehicle Ad hoc NETwork (VANET) is developed as a part of ITS to support the variety of applications such as road safety, infotainment. VANET is formed as the self-organized network between vehicles or between vehicle to centralized infrastructure (called Road Side Unit (RSU)). VANET consists of two types of communications: Vehicle-to-vehicle (V2V) and Vehicle-to-RSU (V2R) communications. To enhance the safety, reduce traffic accidents,

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and improve transportation efficiency, VANET supports mainly applications: safety and non-safety applications [1,2]. The non-safety application contains information, advertisements, and entertainment for users while traveling. The safe application is an important VANET application which can enhance the public safety standards and provide a safer environment for people on the road. The safe application includes intersection collision warning, transit vehicle signal priority, work zone warning. The safety and non-safety applications are summarized in Table 1 as well as their requirements.

Table 1. DSRC application requirements [3,4].

Applications	Packet size/bandwidth	Latency (ms)	Network data type	Application range (m)	Priority
Intersection collision warning/avoidance	100 bytes	100	Event	300	Safety of life
Cooperation collision warning	100 bytes/10 Kbps	100	Periodic	50–300	Safety of life
Work zone warning	100 bytes/1 Kbps	1000	Periodic	300	Safety
Transit vehicle signal priority	100 bytes	1000	Event	300–1000	Safety
Toll collections	100 bytes	50	Event	15	Non–safety
Service announcements	100 bytes/2 Kbps	500	Periodic	0–90	Non-safety
Movie download (2 hours of MPEG 1)	>20Mbps	NA	NA	0–90	Non-safety

Medium Access Control (MAC) protocol is designed to efficient and reliable safety packets transmission. MAC protocols are proposed based on Time Division Multiple Access (TDMA) [5–9]. Space Division Multiple Access (SDMA) [10,11], Code Division Multiple Access (CDMA) [12,13] and Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) such as IEEE 802.11 [14]. TDMA-based MAC protocols operate in a time-slotted structure. Each node must exactly occupy one time slot in each TDMA-based period. TDMA-based MAC protocols allow that each node transmits its packet without any collisions. Hence, they can support reliable broadcasting safety services. On the other hand, the CSMA-based MAC protocols allow that when a vehicle has a packet to transmit, it randomly attempts to access the channel. CSMA-based MAC protocols can provide different Quality of Service (QoS) for non-safety applications. Recently, the MAC protocols employing both CSMA and TDMA-based MAC schemes into one scheme is proposed, called hybrid MAC protocol. These protocols provide a high QoS and reduce the collision rate.

One issue of designing MAC protocols is that how to adapt them to various scenarios in which speeds and densities are frequently changing. Approaches can solve this issue by reducing the length of interval based on traffic condition based on Markov chains [15–18], vehicle density [19–21], reserved time slot [4,22–24]. These protocols improve the system throughput and reduce the

safety packet delay. In this survey, we concentrate to hybrid MAC protocols using dynamic TDMA-based periods. Compared another MAC protocols using dynamic TDMA-based periods, hybrid MAC protocols not only provide a high QoS for non-safety services but also increase safety packet delivery ratio.

2 Adaptive TDMA and CSMA-Based MAC Protocols

The United States Federal Communication Commission (FCC) has allocated 75-MHz radio spectrum for Dedicated Short Range Communications (DSRC) in VANETs which use V2V and V2R communications. The DSRC consists of seven channel: one Control CHannel (CCH) and six Service CHannels (SCHs). The CCH is used to transmit control information and high-priority short safety packets. On the other hand, the SCHs are used to transmit safety and non-safety packets. The CCH divide into two periods: Control CHannel Interval (CCHI) and Service CHannel Interval (SCHI). Each vehicle tunes to CCHI to transmit control information and high-priority short safety packets. During SCHI, vehicles switch to any chosen specific SCH to deliver non-safety messages.

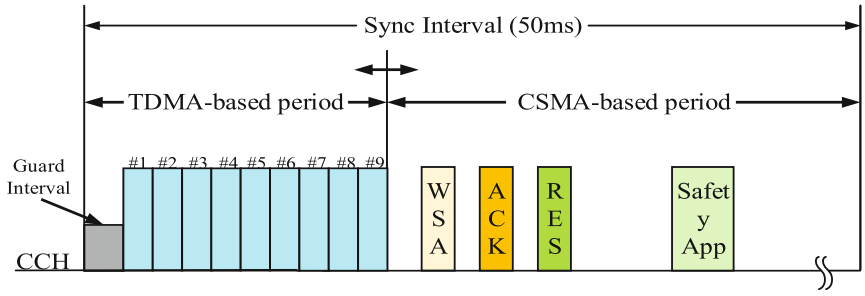

Fig. 1. The operation of adaptive TDMA and CSMA-based MAC protocols.

The hybrid MAC protocols divide CCHI into two periods: TDMA-based period (TP) and CSMA-based period (CP), as shown in Fig. 1. TDMA-based period is defined as the period contains time slots and each node will access using TDMA mechanism. Otherwise, a CSMA-based period is defined as during this period each node having data will randomly attempt to access channel. Note that, each node will broadcast its beacon during its reserved time slot in TP. The WAVE Service Advertisements (WSA) and high-priority safety application are transmitted during CP. The hybrid MAC protocols can improve safety message broadcast and increase throughput on the CCH.

In dynamic scenarios, the length of TP can be optimized to improve the throughput of non-safety packets and increase packet delivery ratio of safety packets. When the vehicle density is low, the node can self-organizes to reduce the length of TP. When the vehicle density is large, the length of TP can

increase to guarantee all vehicles occupy one time slot. We divide into two main methods: self-organized method and RSU-coordinated method. According to self-organized method, DMMAC [22], HER-MAC [4], HTC-MAC [23], EFAB [24] protocols were proposed. The C-MAC [25] protocol based on the RSU-coordinated method to assign a time slot for each vehicle in RSU's coverage area. The classification of adaptive TDMA and CSMA-based MAC protocols is shown in Fig. 2.

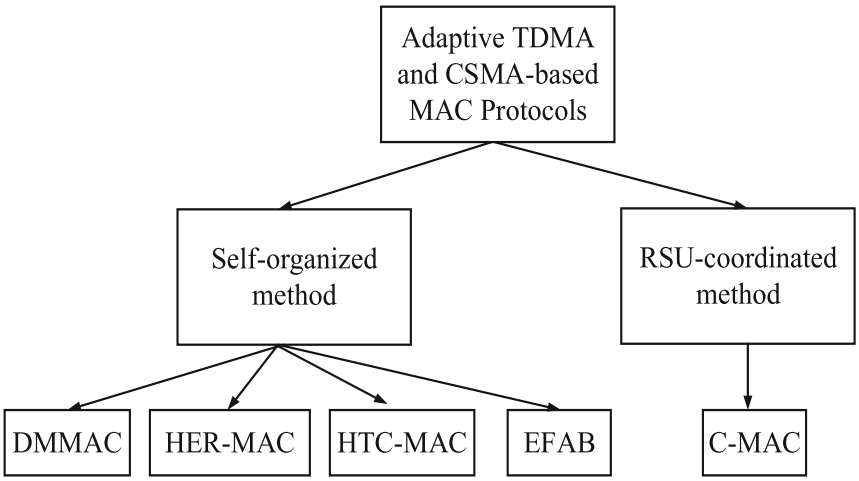

Fig. 2. Classification of adaptive TDMA and CSMA-based MAC protocols.

2.1 A Dedicated Multi-channel MAC Protocol

During a reserved time slot in DMMAC [22] protocol, each node will broadcast its frame information including it length information of TP and each time slot information (busy status and transmitting vehicle identifier). Nodes record this information after each Sync Interval (SI). A node, x, which occupied the last time slot in the TP, becomes a quasi-switcher. If there is an available time slot, x will mark this time slot as BUSY. After one frame, if one-hop neighbors confirm BUSY and x in the field of that time slot, x successfully switch to a new time slot. DMMAC protocol not only adapt itself to various traffic conditions but also allows vehicles can transmit safety packet without wait until the end of a frame. However, the access and merging collisions are not considered and this simulation results only take place in the simple highway.

2.2 A Hybrid Efficient and Reliable MAC Protocol

Unlike DMMAC, a node, x, occupying the last time slot in TP will broadcast SWITCH packet to move to an available time slot in HER-MAC [4]. During CP, safety, HELLO and SWITCH packets are transmitted. In TP, each node will

broadcast its beacon including the TP's information which is represented by the bit-mapped information. HER-MAC protocol improves the throughput for the non-safety packets and the packet delivery ratio for the safety packet. Therefore, because there are many types of packets transmitted in the CP, when the vehicle density is large, the collision is increased.

2.3 An Efficient Time Slot Acquisition on the Hybrid MAC Protocol

HTC-MAC [23] protocol enhances the HER-MAC protocol to improve the throughput for non-safety packets. During the CP, the WSA/ACKnowledgment (ACK)/Response (RES) or Request For Service (RFS)/ACK/RES packets are transmitted between senders and receivers. A node, x, occupying the last time slot in TP will include its IDentifier (ID) and corresponding time slot into its beacon to move to a new time slot. As shown in Fig. 3, nodes d and g will move to time slot #2 in next SI. HTC-MAC can improve the system throughput and efficient time slot acquisitions. However, when vehicle density is large, the overhead of beacon packet increases and the length of time slots is greater.

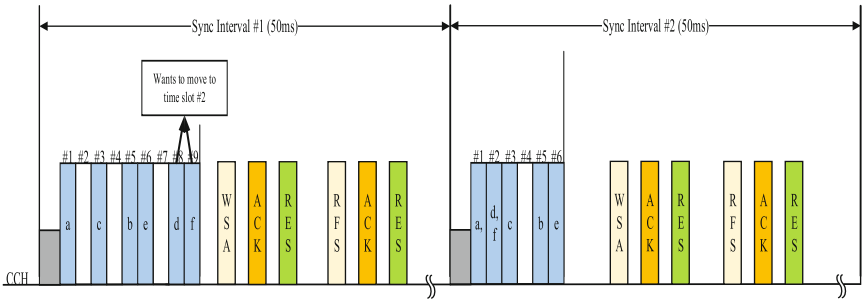

Fig. 3. Operation of HTC-MAC protocol.

2.4 An Efficient and Fast Broadcast Frame Adjustment Algorithm in the Hybrid MAC Protocol

Unlike DMMAC, HER-MAC and HTC-MAC protocol, EFAB protocol does not consider to the node occupying the last time slot in TP. The first node transmitting among one-hop neighbors set in CP will suggest nodes that can move to a new time slot. As shown in Fig. 4, node a, which is the first transmitting node in its one-hop neighbors set, suggests that nodes f and e move to new time slot. Node c suggests that node d moves to a new time slot #2. If one-hop neighbor vehicles confirm about this suggestion, these nodes will move to new time slot in next SI. EFAB protocol can improve the packet delivery ratio of WSA packets and support efficient and fast broadcast frame adjustment.

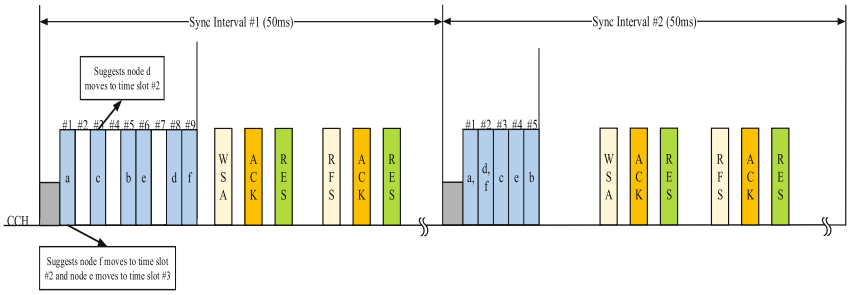

Fig. 4. Operation of EFAB protocol.

2.5 Coordinated Multi-channel MAC Protocol

On the other hand, C-MAC [25] protocol is based on RSU-coordinated method. The CCHI is divided into three periods: Length Information Broadcast Phase (LIBP), Safety Message Phase (SMP), and Channel Reservation Phase (CRP), as shown in Fig. 5. SMP uses TDMA-based mechanism while CRP uses CSMA-based mechanism. The RSU will broadcast Length Information (LI) during LIBP which contains the length of SP and vehicle's ID and corresponding order of time slot. Each vehicle will broadcast its packet during a time slot which is assigned by RSU. The three-way handshake with Request (REQ), Response (RES), and RSU Coordination (RC) packets are transmitted during CRP. A new node moving into RSU's coverage area will randomly choose a time slot in SCHI after it receives control slot (CS) packet transmitted by RSU. The RSU knows the ID's vehicle and includes them into the LI packet for the next synchronization interval. After SCHI ends, the RSU broadcasts an LI packet

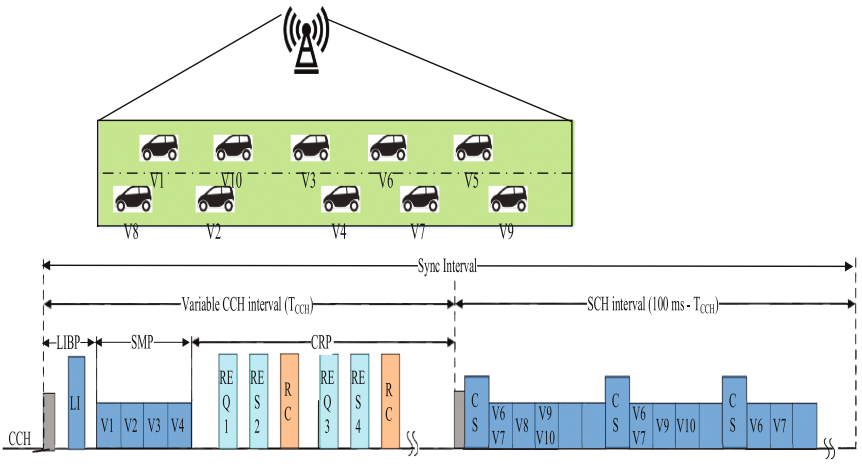

Fig. 5. Operation of CMAC protocol.

during the LIBP in the new synchronization interval to announce the LI of each phase and the transmission order during the SMP [25]. CMAC protocol improves the system throughput and delay of safety packet transmission. However, CMAC protocol operates the only area where RSU is placed.

3 Challenges in Adaptive TDMA and CSMA-Based MAC Protocols

We introduce some open issues and possible directions for future research as follows.

1. **Multi-channel operation**: Most adaptive TDMA and CSMA-based MAC protocols only operate only a single channel (control channel). However, DSRC channel consists of seven channels. Hence, future MAC protocol needs to enhance to multi-channel operations.
2. **Merging collision**: Merging collision is defined as the collision occurs among vehicles which have successfully acquired a time slot and are moving to other transmission range. Existing adaptive TDMA and CSMA-based MAC protocols cannot avoid this collision. In future, designing MAC protocol solve this problem and improve the system throughput.
3. **Optimal length of CSMA-based period**: It is possible to optimize the length of CSMA-based period by using Markov chains method. Some approaches, such as MP MAC [16,26], VCI MAC [17], Q-VCI MAC [27] and CAMAC [28,29] are proposed to reduce the length of the CSMA-based period.

4 Conclusion

Adaptive TDMA and CSMA-based MAC protocols not only improve the throughput for non-safety packets but also support efficient and reliable safety packet. By employing TDMA and CSMA-based mechanisms, each node can transmit safety packet without any collisions during its time slot while it can randomly attempt to access channel to transmit WSA packets on the CSMA-based period. The length of the TDMA-based period can be adjusted by the self-organized method or assigned by RSU. The dynamic TDMA-based period makes TDMA and CSMA-based MAC protocol can adapt itself to different traffic conditions. In future, TDMA and CSMA-based MAC protocol needs to satisfy various QoS requirement of non-safety services.

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